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# Aerodynamic Characteristics of Wheelchairs

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## SUMMARY

An experimental study was conducted in the Langley V/STOL tunnel to determine the aerodynamic drag characteristics of a conventional wheelchair. The study was conducted at the request of the Rehabilitation Engineering Center of the University of Virginia which is operating under a grant from the U.S. Department of Health, Education, and Welfare.

The study has defined the overall aerodynamic drag characteristics and has further determined the individual drag contributions of the various wheelchair components. The results show that a fiftieth percentile man sitting in the complete wheelchair would experience an aerodynamic drag coefficient on the order of 1.4.

## INTRODUCTION

Rehabilitation centers are currently attempting to define the physical and physiological capacity required for individuals handicapped to varying degrees to safely propel a wheelchair. Rehabilitation centers are also actively engaged in research for alternate wheelchair propulsion techniques and systems, the intended outcome of such research being to provide handicapped individuals with increased mobility. At the onset of such a research effort, a knowledge of the retarding forces (both aerodynamic and frictional) is required. Estimates of aerodynamic drag would indicate that under typical wheelchair operating conditions (for example, speeds on the order of 0.9 to 1.3 m/sec (2 to 3 mph)) the retarding force would be almost exclusively frictional. However, under adverse head-wind conditions, aerodynamic drag may be significant, particularly in the case of wheelchair users with only marginal physical and physiological capacities.

The present study was conducted at the request of the Rehabilitation Engineering Center of the University of Virginia which is operating under a grant from the U.S. Department of Health, Education, and Welfare. The study is intended to determine the basic aerodynamic drag characteristics of a manned conventional wheelchair (to validate currently estimated values) and to determine the drag contribution of the wheelchair component parts.

## SYMBOLS

The data are referred to the stability system of axes as illustrated in figure 1. The wheelchair geometric characteristics and the moment reference center are illustrated in figure 2.

The dimensional quantities herein are given in both the International System of Units (SI) and U.S. Customary Units.

A	frontal area of wheelchair, hw	0.465 m <sup>2</sup> (5.013 ft <sup>2</sup> )
C <sub>D</sub>	drag coefficient,	$\frac{\text{Drag}}{qA}$
C <sub>L</sub>	lift coefficient,	$\frac{\text{Lift}}{qA}$
C <sub>m</sub>	pitching-moment coefficient,	$\frac{\text{Pitching moment}}{qAl}$
h	height of wheelchair used in area calculation,	0.873 m (2.865 ft)
l	wheelbase of wheelchair,	0.394 m (1.292 ft)
q	free-stream dynamic pressure,	$\frac{1}{2}\rho V^2$ , Pa (lbf/ft <sup>2</sup> )
V	free-stream velocity,	m/sec (ft/sec)
w	width of wheelchair used in area calculation,	0.533 m (1.75 ft)
ρ	free-stream density,	kg/m <sup>3</sup> (slugs/ft <sup>3</sup> )

#### MODEL AND APPARATUS

A commercially available wheelchair (fig. 2) was used for the investigation. The chair back and seat, which are normally constructed of a flexible material, were replaced with 0.3175 cm (0.125 in.) thick aluminum sheet to prevent distortion under aerodynamic load and to provide a rigid attachment surface for a standard strain-gage balance. A polystyrene manikin (fig. 3(a)) was constructed to represent a fiftieth percentile man (see ref. 1).

#### TEST CONDITIONS

The tests were conducted in the Langley V/STOL tunnel for a nominal range of velocities of about 3.5 to 13 m/sec (11.5 to 43 ft/sec). The lowest value of velocity was determined by tunnel operational constraints. The wheelchair (fig. 3) was sting mounted and an electrical pitch indicator was installed so that the wheelchair could be leveled before the forces and moments were measured. Limited tests were conducted with the wheelchair located approximately 2.5 cm (1 in.) above the tunnel floor; however, the majority of tests were conducted with the wheelchair approximately on the wind-tunnel vertical center line.

## TEST RESULTS

A limited number of tests were conducted with the wheelchair located about 2.54 cm (1.0 in.) above the wind-tunnel floor. While this mounting arrangement would accurately simulate the actual condition of a wheelchair being subjected to head wind and would include ground effects, it also presents a potential fouling problem. Comparison of these data with corresponding data for the wheelchair mounted on the wind-tunnel vertical center line (and hence out of ground effects) showed that for this configuration ground effects are negligible. (See ref. 2 for a discussion of ground effects on the aerodynamic characteristics of automobiles.) Having determined that ground effects could be ignored, the remainder of the tests were conducted with the model located on the wind-tunnel vertical center line and the data presented herein correspond to that condition.

### Aerodynamic Characteristics of Complete Wheelchair Without Manikin

The longitudinal force and moment coefficients of the complete wheelchair (fig. 2) are presented in figure 4 as a function of free-stream dynamic pressure. The results presented show that for the range of dynamic pressures considered, the force and moment coefficients are essentially constant.

Also, from figure 4, it can be seen that the average value of drag coefficient for the complete chair is about 0.96. This value is considered to be in good agreement with engineering estimates of  $C_D = 1.0$ , which would be approximated on the basis of material contained in reference 3. It should be further noted that the wheelchair is also subjected to a moderate downward force (negative lift), which would result in increased friction drag. This negative lift simply results from the chair back acting like a large-chord, upwardly deflected, trailing-edge flap.

### Aerodynamic Characteristics of Complete Wheelchair With Manikin

The complete wheelchair was tested with a manikin which was representative of a fiftieth percentile man (ref. 1). The manikin was tested with both tight and loose fitting clothes as shown in figure 5. The results are summarized in table I and show, as expected, a substantial increase in drag due to the presence of the manikin and an additional small increase in drag due to the loose clothes. The measured values of drag for the complete wheelchair with the manikin are on the order of  $C_D = 1.4$ . This value is in good agreement with engineering estimates of  $C_D = 1.5$ , which would be approximated on the basis of material contained in reference 3.

### Aerodynamic Characteristics Determined From Component Buildup Studies

In order to determine the contribution of the various wheelchair components to the overall drag characteristics, configuration buildup studies were conducted. The various configurations studied are shown in figure 6, and the results are summarized in table II. As expected, the chair back is the most

substantial contributor to drag and is also responsible for the negative lift force noted previously. It should be noted that the drag coefficient of the other components is substantial, which suggests that the overall drag coefficient could be reduced by attention to design; for example, streamlined tubing and wheel fairings could be introduced. (See ref. 3.)

#### Aerodynamic Characteristics of Wheelchair With Modified Back

As noted in the previous section, the wheelchair back is the largest contributor to aerodynamic drag. In an attempt to reduce the level of drag by permitting air to be vented around the manikin, a modified chair back (see fig. 7) was introduced. The results of this phase of the investigation are summarized in table III. These results show that the modified back results in significant reductions in  $C_D$  when no manikin is present. However, with the manikin in place (with loose clothes) the beneficial effect of the modified chair back is lost.

#### ANALYSIS OF RESULTS

The results of the previous section have shown that a fiftieth percentile man sitting in a complete wheelchair would experience an aerodynamic drag coefficient on the order of 1.4. The following analysis is intended to illustrate the influence of this aerodynamic drag on the total force and power required for an individual to overcome a steady head wind. The analysis assumes a steady wheelchair velocity, relative to the ground, of 0.894 m/sec (2 mph) on a horizontal surface. The assumed combined weight of the individual and the wheelchair is 890 N (200 lbf). The assumed tire pressure is 275 790 Pa (40 lbf/in<sup>2</sup>).

On the basis of the method presented in reference 3, the frictional force is determined to be 7.784 N (1.75 lbf). This result is in good agreement with unpublished measurements obtained at the Rehabilitation Engineering Center of the University of Virginia. The aerodynamic drag is simply determined from the relationship

$$\text{Aerodynamic drag} = \frac{1}{2} \rho V^2 A C_D$$

where the velocity  $V$  used for calculation purposes is the relative velocity (i.e., the sum of the velocity of the wheelchair relative to the ground and the head-wind velocity). The results of these calculations are presented in figure 8 and show that for head winds on the order of 3.1 m/sec (7 mph) the aerodynamic drag is equal to the frictional drag.

The results of figure 8 are used to determine the power required to overcome a steady head wind. The power required to overcome the friction drag (while maintaining a velocity relative to the ground of 0.894 m/sec (2 mph)) is simply given by

$$\text{Power} = (\text{Friction drag}) (\text{Velocity relative to ground})$$

and the power required to overcome the aerodynamic drag is simply given by

$$\text{Power} = (\text{Aerodynamic drag}) (\text{Relative velocity})$$

where the relative velocity is the sum of the head-wind velocity and the wheel-chair velocity relative to the ground. The results of these calculations are presented in figure 9.

Unpublished studies conducted by the Rehabilitation Engineering Center of the University of Virginia indicate that a healthy individual can supply a continuous power on the order of 125 watts (1/6 horsepower). On the basis of the results presented in figure 9, it can be seen that such an individual would be unable to progress at a rate of 0.894 m/sec (2 mph) for head winds above 5.6 m/sec (12.5 mph). Furthermore, the same healthy individual would be unable to make any progress for head winds above 6.7 m/sec (15 mph).

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November 30, 1979

#### REFERENCES

1. Dreyfuss, Henry: The Measure of Man; Human Factors in Design. Second Ed. Whitney Library of Design, 1967.
2. Turner, Thomas R.: Wind-Tunnel Investigation of a 3/8-Scale Automobile Model Over a Moving-Belt Ground Plane. NASA TN D-4229, 1967.
3. Hoerner, Sighard F.: Fluid-Dynamic Drag. Hoerner Fluid Dynamics (Brick Town, N. J.), c.1965.

TABLE I.- AERODYNAMIC COEFFICIENTS FOR WHEELCHAIR  
WITH AND WITHOUT MANIKIN

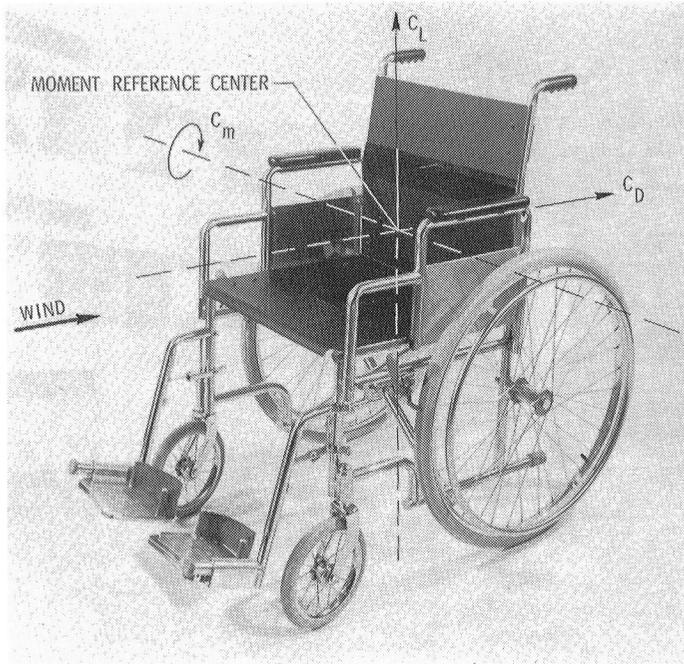
Configuration	Figure	$C_D$	$C_L$	$C_m$
Complete wheelchair . . . . .	2	0.96	-0.40	-0.20
Complete wheelchair with manikin (tight clothes) . . .	5(a)	1.34	-0.44	-0.22
Complete wheelchair with manikin (loose clothes) . . .	5(b)	1.45	-0.43	-0.29

TABLE II.- AERODYNAMIC COEFFICIENTS DETERMINED FROM  
 COMPONENT BUILDUP STUDIES

Configuration	Figure	$C_D$	$C_L$	$C_m$
Frame . . . . .	6(a)	0.22	-0.05	-0.05
Frame, wheels . . . . .	6(b)	0.37	-0.03	-0.17
Frame, wheels, arm rests . . . . .	6(c)	0.40	-0.04	-0.17
Frame, wheels, arm rests, foot rests . . . . .	6(d)	0.45	-0.01	-0.13
Complete wheelchair . . . . .	2	0.96	-0.40	-0.20
Complete wheelchair with manikin (tight clothes) . . . . .	5(a)	1.34	-0.44	-0.22
Complete wheelchair with manikin (loose clothes) . . . . .	5(b)	1.45	-0.43	-0.29

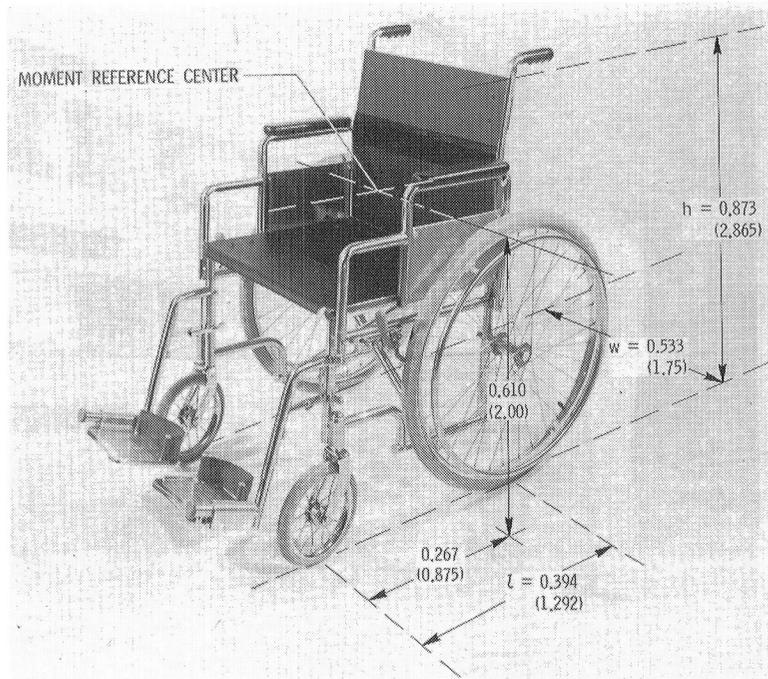
TABLE III.- AERODYNAMIC COEFFICIENTS  
FOR MODIFIED WHEELCHAIR

Configuration	Figure	$C_D$	$C_L$	$C_m$
Complete wheelchair . . . . .	2	0.96	-0.40	-0.20
Complete wheelchair with modified back . . . . .	7	0.64	-0.02	-0.09
Complete wheelchair with manikin (loose clothes) . .	5(b)	1.45	-0.43	-0.29
Complete wheelchair with modified back and manikin (loose clothes) . . . . .		1.38	-0.42	-0.26



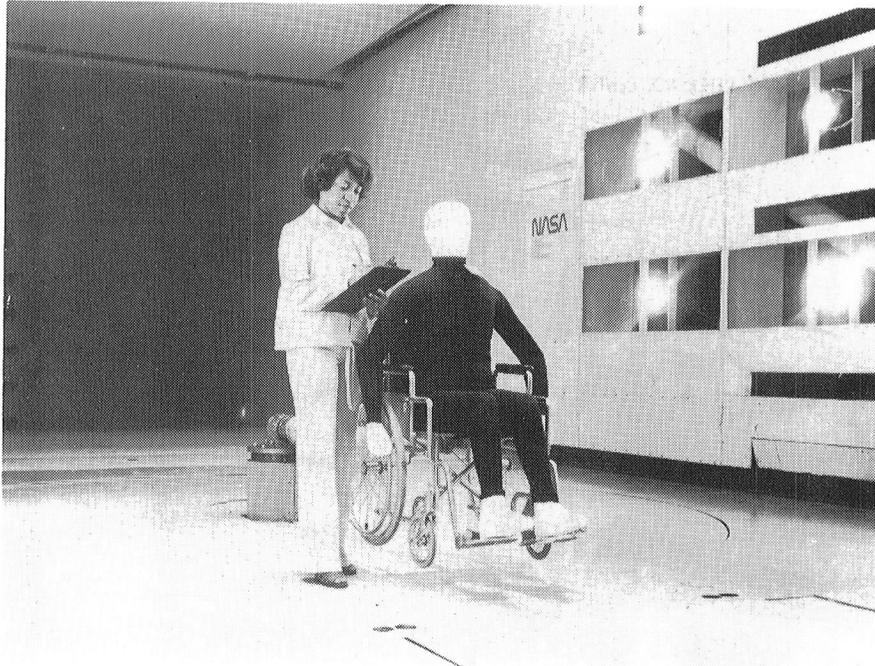
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Figure 1.- System of axes.



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Figure 2.- Geometric characteristics of wheelchair. Dimensions are given in meters and parenthetically in feet.



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(a) Wheelchair with manikin.



L-79-5072

(b) Wheelchair without manikin.

Figure 3.- Wheelchair mounted in Langley V/STOL tunnel.

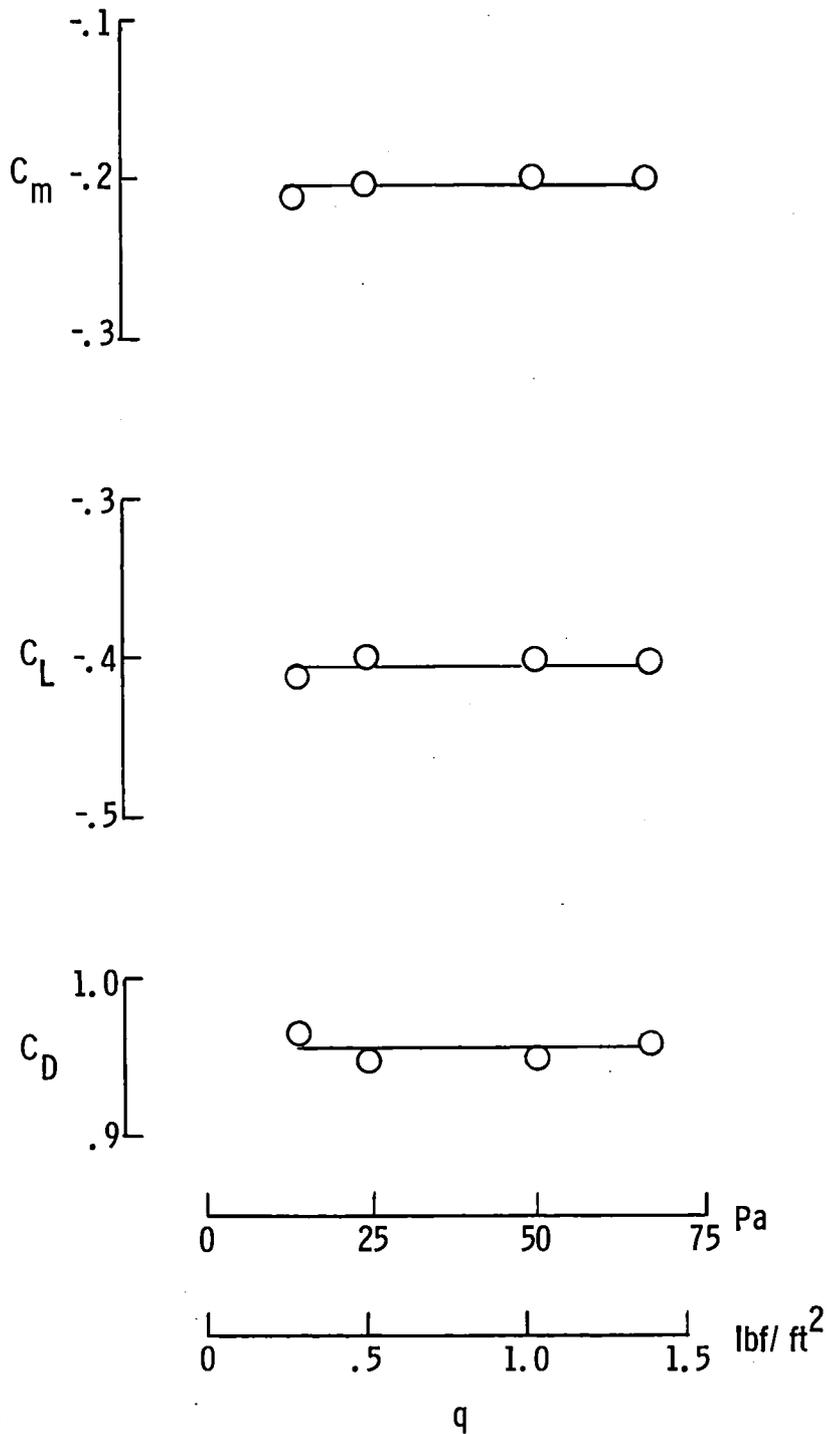


Figure 4.- Effect of free-stream dynamic pressure on longitudinal aerodynamic characteristics of complete wheelchair.



L-79-5374

(a) Manikin in tight clothes.



L-79-5376

(b) Manikin in loose clothes.

Figure 5.- Manikin in wheelchair.



L-79-5371

(a) Frame.



L-79-5380

(b) Frame and wheels.

Figure 6.- Wheelchair component combinations studied.



L-79-5381

(c) Frame, wheels, and arm rests.



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(d) Frame, wheels, arm rests, and foot rests.

Figure 6.- Concluded.



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Figure 7.- Complete wheelchair with  
modified back.

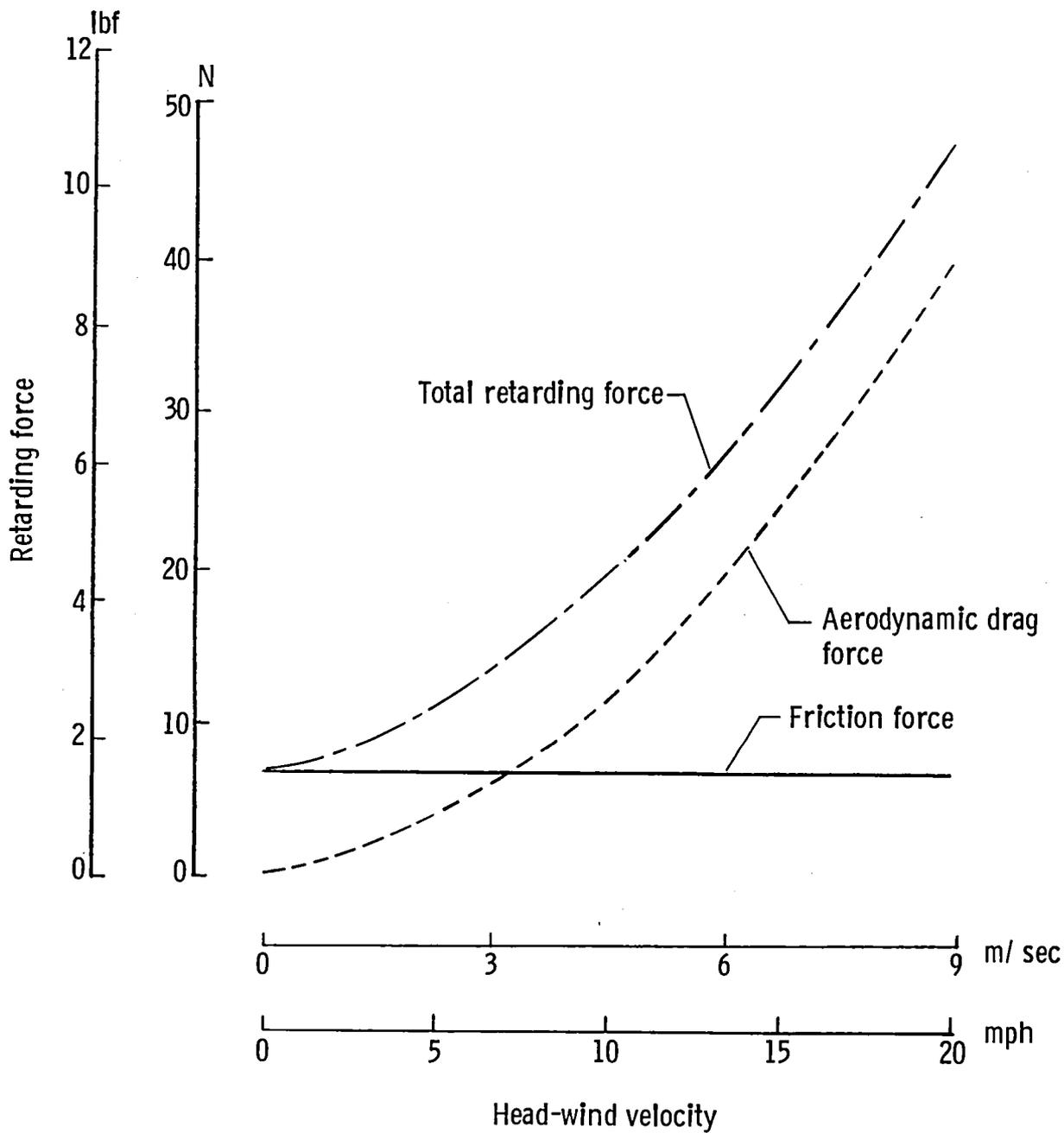


Figure 8.- Variation of retarding force with head-wind velocity.

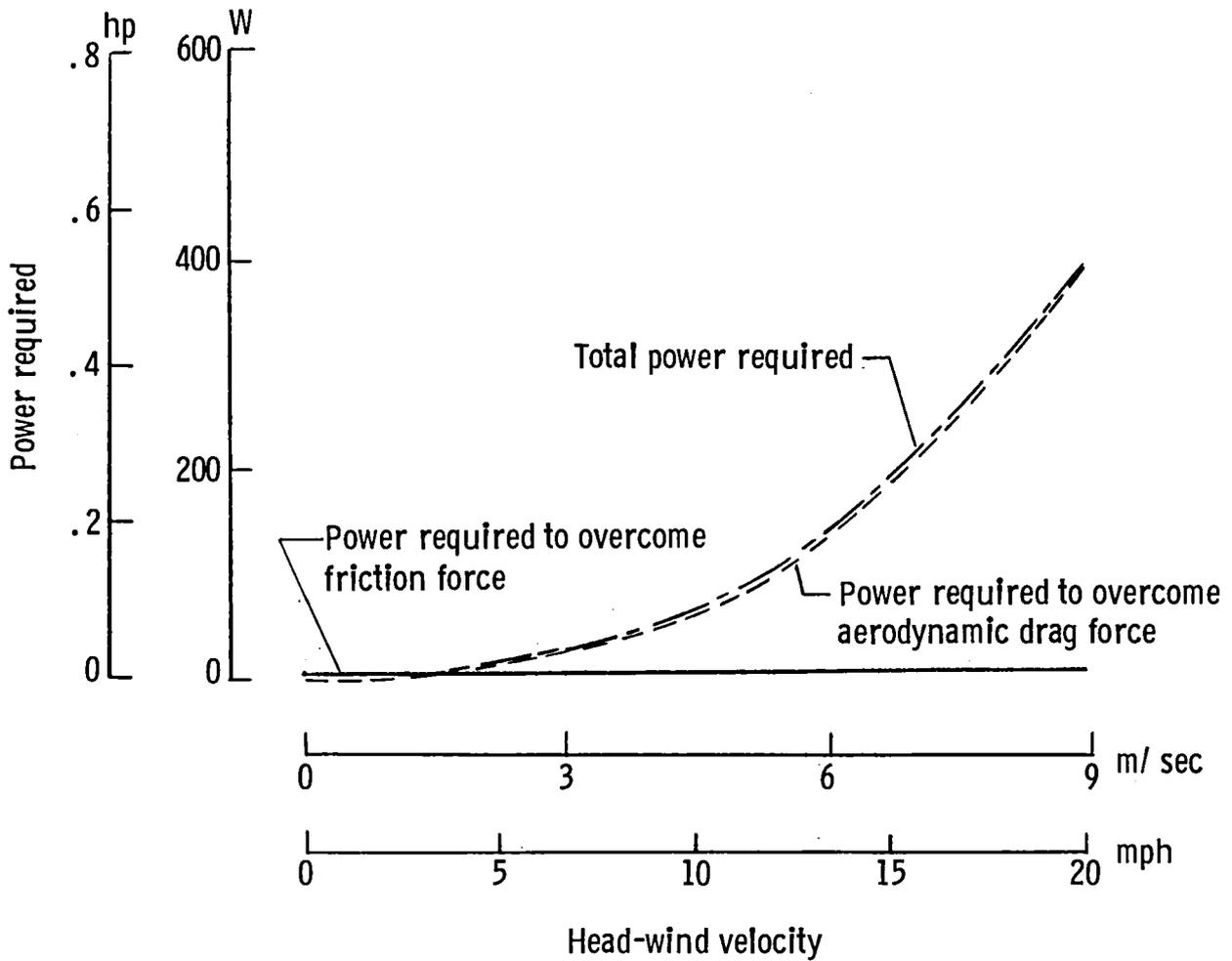


Figure 9.- Variation of power required to overcome retarding force with head-wind velocity.

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